Clock Requirements for Gamma-Ray Burst Localization Experiments

Dave Van Buren, California institute of Technology

Abstract. Precise localization of gamma-ray bursts requires accurate timing information. A feasible space experiment places a number of detectors in the inner solar system with AU separations. To attain arcsecond positions, clock accuracy must be held to 1 millisecond. Mission costs are significantly reduced if the clock drift can be held to 1 millisecond over the entire mission, *i.e.* for several years.

Gamma-ray Bursts

Gamma-ray bursts are intense impulsive radiative events taking place outside our solar system with a rate of once per day at the detection limit of current experiments. If located at cosmological distances, a distinct possibility, then they are the most energetic events known in the Universe. Their properties have been the subject of study and debate for nearly three decades, since their discovery by satellites monitoring the nuclear test ban treaty. For an early discussion, see Ruderman (1975). A set of good recent reviews are available on the Web by Fishman (1995), Paczynski (1995), and Lamb (1995) which lay out the open issues.

There is strong consensus that the most important question to be answered is what are the objects responsible for gamma ray bursts. Attempts to associate various classes of objects using the rather large error regions currently available have all met with failure. These error regions are so large that even the smallest have thousands of objects contained within their boundaries in the deepest images. Progress requires narrowing the error regions to the arcsecond scale, a scale so small that only a single astrophysical object is likely to be present.

Localization via Timing

Arrival directions for gamma ray events are most accurately determined via time of arrival analysis of the wavefront at widely dispersed detectors. Aperture masking techniques can also give modest directional information over limited fields of view. In a timing experiment, the delays in arrival time between different detectors at different positions constrain the location on the sky. A single time of arrival of course contains no position information. A pair, yielding a single delay gives as allowed positions all points on the circle marking the intersection of a cone with the celestial sphere. The axis of the cone is oriented along the displacement vector between the two spacecraft. The circle becomes a band of some width when timing uncertainties are taken into account. Two pairs, from three detectors give a pair of intersecting bands, which yield a 2-fold ambiguity for the source position. Four non-coplanar detectors are needed to give a single simply-connected error region on the sky.

Clock Requirements

The fastest time scales t observed in gamma ray bursts are about 1 millisecond. To attain an angular accuracy $d\theta$ over a detector array with linear extent L needs clocks good to

$$\frac{dt}{1\ \mathrm{ms}} = 0.4\,\frac{d\theta}{1\ \mathrm{arcsec}}\,\frac{L}{1\ \mathrm{AU}}$$

Detectability considerations require that sufficient gamma rays are counted to accurately determine the event timing, leading to very large detectors for L corresponding to earth-orbiting arrays, anti small "pop-can" detectors for a mission to the edge of the solar system. For 1 millisecond timing resolution, one requires detector areas of several hundred cm^2 and $L \approx 1$ AU, which can be packaged into a 20 kg spacecraft, i.e. a very attractive experiment cost-wise. This mass is chosen so that to first order the spacecraft serves the needs of the detector, rather than the clock.

An experiment of this kind would yield arcsecond positions of one to a few bursts per month once the array is deployed to $L = 1$ AU. It takes some time to get to this size though, depending on the velocity imparted by each spacecraft's final stage. To remain in earth-like orbits around the sun for thermal and telecommunications reasons requires a relatively small kick, giving deployment times of about 1 year. This puts a stability requirement on the clock of drifts less than 1 0^{-1}] over a course of a several year mission life.

Another requirement comes from the small spacecraft size. A 20 kg spacecraft will have a limited area available for solar panels to generate power unless costly panel deployment schemes are employed. Much of the power budget will be required for the telecommunications system to get the data to the ground, detectors ancl CPU, leaving little left over for the clock. Out of perhaps 10 W of power, only 1 W will be available for the clock.

Also flowing down from the need for a small spacecraft is the requirement of small clock mass. The clock must be less than 1 kg.

Exceeding these performance numbers will yield the following benefits: increased stability will help achieve more precise positions, the solid angle goes as dt^2; reducing the power requirement will allow slightly longer baselines to be achieved via larger orbits which carry the spacecraft to regions of lower solar illumination; lower mass clocks marginally improve the experiment by either achieving slightly larger L, or by slightly increasing the detector sensitivity by making them a bit larger. In the latter regard, note that the next generation of detectors themselves will provide a performance per unit mass improvement of a factor of 2-5, making a small savings in clock mass potentially translate to a large gain in detector area for the same total package mass.

Once the quoted requirements are met, improvements in clock stability will give the most benefit since the clocks are already minor components of the mass and power budgets. One can anticipate the availability of space qualifiable clocks with these properties in the near term, enabling a gamma-ray burst localization experiment of unprecedented accuracy to be undertaken for low cost.

Acknowledgements

This work was funded by the National Aeronautics and Space Administration via a contract, to the Jet Propulsion Laboratory of the California Institute of 'J'ethnology. I thank the conference organizers for the opportunity to present these thoughts.

References

Fishman, G. J., 1995, http://antwrp.gsfc.nasa.gov/diamond_jubilee/papers/fishman.html.
Lamb, D. Q., 1995, http://antwrp.gsfc.nasa.gov/diamond_jubilee/papers/lamb/lamb.html.
Paczynski, B. A., 1995, http://antwrp.gsfc.nasa.gov/diamond_jubilee/pac/lamb/debate.html.
Ruderman, M., 1975, Ann. N.Y.Acad.Sci., 262, 164.